VLA[1] Observations of Radio Variability of ER Vulpeculae in 1995

Slavek M. Rucinski[2]
Electronic-mail: *rucinski@cfht.hawaii.edu*
Canada – France – Hawaii Telescope Co.
P.O. Box 1597, Kamuela, HI 96743

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ABSTRACT

VLA continuous monitoring of ER Vul during two 11.5 hour sessions in September 1995 in the radio continuum at 3.6 cm (X-band) showed a variation pattern similar to that observed in 1990 and 1991, but at a lower mean flux level. Simultaneous observations with the EUVE satellite in the 70 – 140 Å band did not show any significant flaring variability of the star.

1. INTRODUCTION

ER Vulpeculae (HD 200391) is a close, short-period (0.7 day) binary system consisting of two solar-type stars locked into synchronous rotation with the rotation rate some 40-times faster than the Sun. The stars are – as expected – very active and show many signatures of magnetic activity, manifested by strong chromospheric and coronal emissions as well as rapidly-evolving, dark photospheric spots. The system was subject to several analyses of its activity, usually in studies including other similar, very active, strongly spotted, short-period binary systems. One of the most recent photometric analyses specifically of this system (which should be referred for previous literature) was by Olah et al. (1994). An extensive spectroscopic study of the system was presented by Hill et al. (1990).

Of all signatures of activity in active stars, radio emission and its variability are the least explored due to very low observed fluxes and the implied necessity of using large radio telescopes. In the case of ER Vul, about 10^{-8} of the bolometric luminosity is converted into the radio emission (Rucinski 1992). Although this bolometric-to-radio flux conversion is some 10^5 times larger than for the solar case and the system is very active and radio-bright, as expected, the observed fluxes are low; for the distance of ER Vul the flux levels are typically $1 - 10$ mJy. Because of these low fluxes, studies of rapid variability require application of 100-meter class radiotelescope, such as the VLA.

[1]The Very Large Array is a facility of the National Radio Astronomy Observatory which is operated by Associated Universities, Inc. under cooperative agreement with the National Science Foundation.

ER Vul was observed before with the VLA radiotelescope system in 1990 and 1991 in a variability-monitoring program described in Rucinski (1992 = R92). This reference should be consulted for earlier literature on the subject and for several details which are omitted in the current paper. The continuum spectral bands were 20 cm (L-band) and 6 cm (C-band) in 1990, whereas most of the 1991 observations were at 3.6 cm (X-band) with only single flux-level checks at 6 cm. Each time, about 23 hours of monitoring were used, in two continuous runs. During each run, the star showed a complex variability pattern, apparently a mixture of short flares typically lasting minutes and continuous variations with time scales of hours. The latter seemed to be partly related to the orbital phases and thus possibly due to optical-depth effects in a complex magnetosphere surrounding both stars. The fluxes at 3.6 and 6 cm were very similar in 1991 suggesting a flat radio spectrum. A drop in the overall radio activity level was noted between 1990 and 1991.

This paper describes 3.6 cm VLA observations of ER Vul in 1995 conducted in a very similar way as in 1990 and 1991. However, in contrast to the previous VLA runs, which did not have any simultaneous support, the 1995 run was scheduled during an Extreme Ultraviolet Explorer (EUVE) program which lasted one week (Rucinski 1998) and provided extreme-ultraviolet spectra of the star. During these observations, the photometric Deep Sky Survey channel (70 – 140 Å) was activated, providing an opportunity of seeking correlations between variabilities in thermal (EUV) and non-thermal (radio) components of the coronal emission. The results are described in Section 3 following the Section 2 about the observations.

2. VLA OBSERVATIONS

The 1995 observations reported in this note were done almost exactly in the same way as in 1991, that is only at 3.6 cm (X-band) and during two 11.5 hour continuous runs. The standard VLA continuum frequencies centered at 8.415 and 8.465 GHz with bandwidths of 50 MHz were used. The main differences relative to the 1991 run were twofold: (1) because of the VLA and the EUVE satellite scheduling constraints, the two sessions were not on consecutive days, but were separated by 3 days; (2) the planned, single, 6 cm (C-band) observations to check the X-band/C-band relative fluxes were inadvertently omitted precluding verification that the C- and X-band fluxes were again comparable in 1995, as they had been in 1991.

The observations were made in equal time intervals of about 15 minutes with the calibration of the scans against the same phase calibrator 2113+293. Individual scans, about 11 − 12 minutes long, were analyzed using the AIPS[2]. Cleaned radio maps were obtained for all scans; then radio emission fluxes were extracted from the maps assuming a point source at the position of ER Vul.

[2]Astronomical Image Processing System (AIPS) is a data-reduction software packages developed by National Radio Astronomy Observatory.

Two different two-dimensional Gaussian fitting routines JMFIT and IMFIT were used for the flux extraction. The data in the two 50 MHz spectral bands were handled separately to obtain quasi-external estimates of the flux errors; the reason for this approach was the fact that the two Gaussian fitting routines are known to give unrealistically small flux errors (R92). Estimation of the errors in this way led to a conclusion that the the peak-flux errors provided by the JMFIT were internally consistent, but that they required an upward scaling by a factor of 4 times for the first run and 4.5 times for the second run. The fluxes tabulated in Table **??** are the average values from both 50 MHz datasets. They are plotted in the upper panels of Figures 1 and 2 (continuous lines) together with the estimates of the errors (broken lines). The data were not analyzed for circular polarization due to the low flux levels; the previous observations (R92) did not show any polarization of the signal.

The times given for the scan mid-points in Table **??** are the heliocentric Julian Days based on the International Atomic Time scale (IAT). To correlate the stellar variability with the orbital orientation of ER Vul, the time shown in Figures 1 and 2 was also expressed in orbital phases counted from the same initial epoch as for the EUVE observations (Rucinski 1998). The ephemeris for the primary (deeper) eclipses was that of Hill et al. (1990): JD(hel) = 2446328.9837 + 0.698095 E, which is apparently still valid, as had been verified one year before our observations by Zeinali et al. (1995). For consistency with the EUVE observations, the epoch E = 5230 was used as the start of the phase count in Figures 1 and 2.

3. RESULTS

The pattern of variability seen during the first run on September 23/24, 1995 was very similar to that seen in the 1990 and 1991 observations, with changes taking place in an hourly time-scale, that in is some 0.1 – 0.2 of the orbital period. The flux levels were very low, close to the typical measurement errors (at or below about 0.3 mJy) at the beginning of the run, but then climbed to about 3 mJy at the end of this run which coincided with the primary eclipse of the binary system. Three days later, on September 26/27, 1997, practically no emission was observed for long time at the orbital phases around the primary eclipse; later, a slight increase was observed at the very end of this day. Thus, during this series of observations, practically no relation to the orbital phases was seen, contrary to what had been observed in 1990 and 1991.

The DSS data in the 70 – 140 Å continuum which were obtained during the radio observations are shown in the lower panels of Figures 1 and 2. The sampling interval used for the DSS photon accumulation was 100 seconds. Such intervals were grouped together by the satellite orbital-visibility periods. The short line segments in the figures connect mean values for such groups in an attempt to accentuate any hourly time-scale variability in the DSS count rate. Although small EUV flares were observed during the whole EUVE run, no significant variability was detected during the portion which overlaped with the radio observations. The DSS data turned out to be consistent with a steady count rate of about 0.14 counts/second. Apparently,

ER Vul was observed during a time when its magnetic activity was generally at a low state.

We note that the DSS light curve obtained during the whole duration of the EUVE run (Rucinski 1998) showed a mild increase in the quiescent level in the phase interval between the primary and secondary eclipses, with a few localized, flare-like increases toward the end of the other half of the orbital period. The active half of the DSS light curve could be related to the highly variable optical light curve in the same phase interval, as observed by Olah et al. (1994) in 1990 – 1992 and possibly also by Zeinali et al. (1995) one year before the VLA observations. We see nothing unusual in this phase interval in the 1995 VLA observations. To the contrary, the radio flux was the lowest in the phase interval between the primary and secondary eclipses.

Concerning the radio flux levels in different years: It is obviously risky to assume that radio emission observed during 23 hours-long runs in 1990, 1991 and 1995 represent typical flux levels. However, if we assume that risk and analyze the observed flux levels in the form of histograms, as in Figure 3, we see a systematic drop over those 6 years. In terms of of the global averages for each program, the mean flux levels were 4.86, 1.16, 0.74 mJy, while the median flux levels were 4.80, 1.05, 0.32 mJy. Unfortunately, we have no other data on activity of ER Vul to correlate these numbers with and to check, if the decrease in the radio emission was accompanied by similar decreases in spot, chromospheric or coronal activities in 1995.

4. CONCLUSIONS

Radio observations of ER Vul in 1995 in the continuum at 3.6 cm gave a very similar picture as during the programs conducted in 1990 and 1991 (R92). Similar type of variability was detected with the dominant slow, hourly time-scale variations at the flux levels between non-detection and about 3 mJy. The average flux levels were the lowest so far observed for the star. The contemporaneous EUV-continuum (70 – 140 Å) observations did not show any detectable variability. While the new observations do not bring any changes to the previous picture established by the more extensive program R92, they will contribute to future studies of long-term radio variability in ER Vul.

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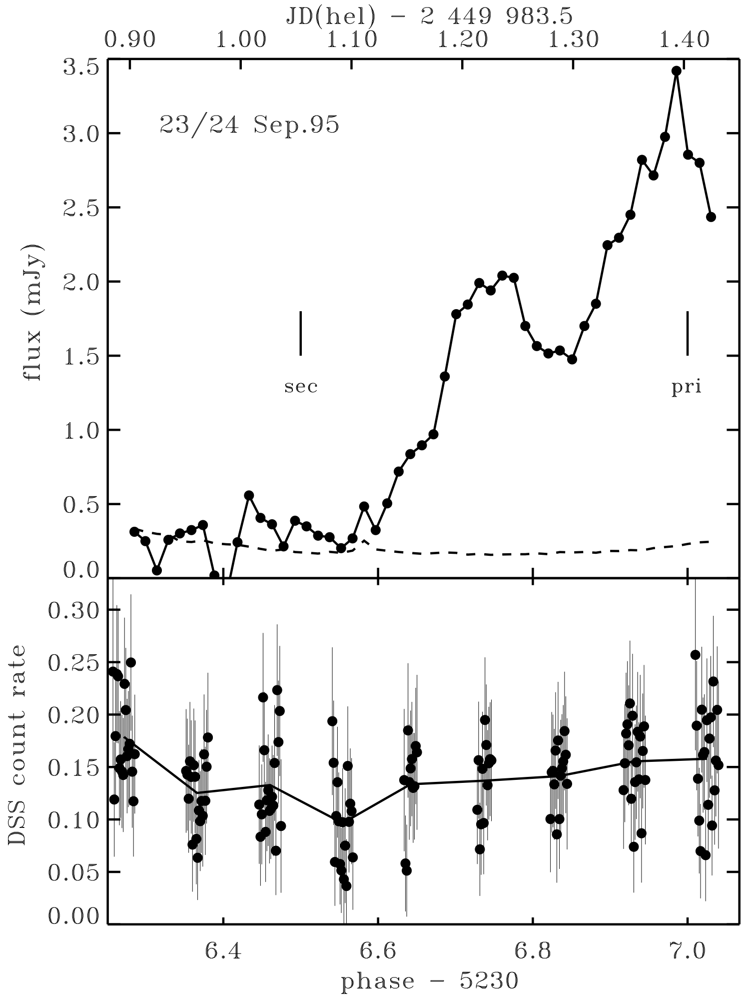

Fig. 1.— Changes of the 3.6 cm continuum flux of ER Vul are shown in the upper panel. The estimated errors of observations are plotted as a broken line. The time axis is in orbital phases counted from an arbitrary epoch of the primary eclipse, as described in the text. The upper horizontal axis gives the time in days since 0^h UT on September 23, 1995. The lower panel shows EUVE observations in the $70 - 140$ Å band, binned in 100 second intervals and expressed as count rates per second. The error bars have lengths equal to two standard errors. The line segments connect the mean count-rate values in groups of data points for each orbital visibility period of the EUVE satellite.

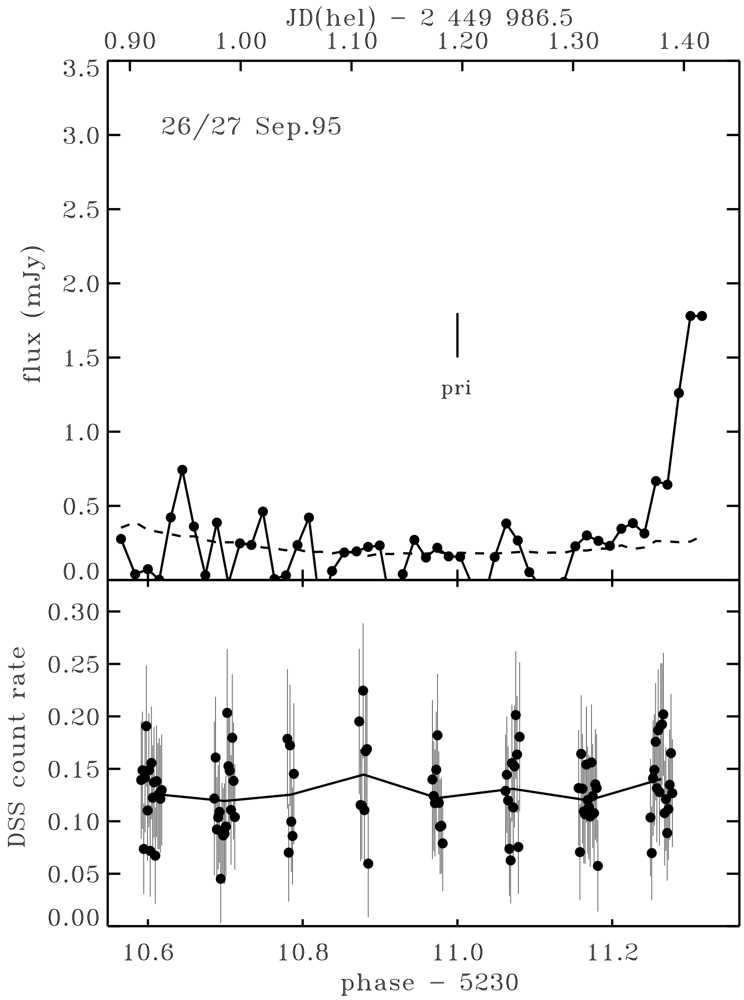

Fig. 2.— The same as in Figure 1, but for September 26, 1995.

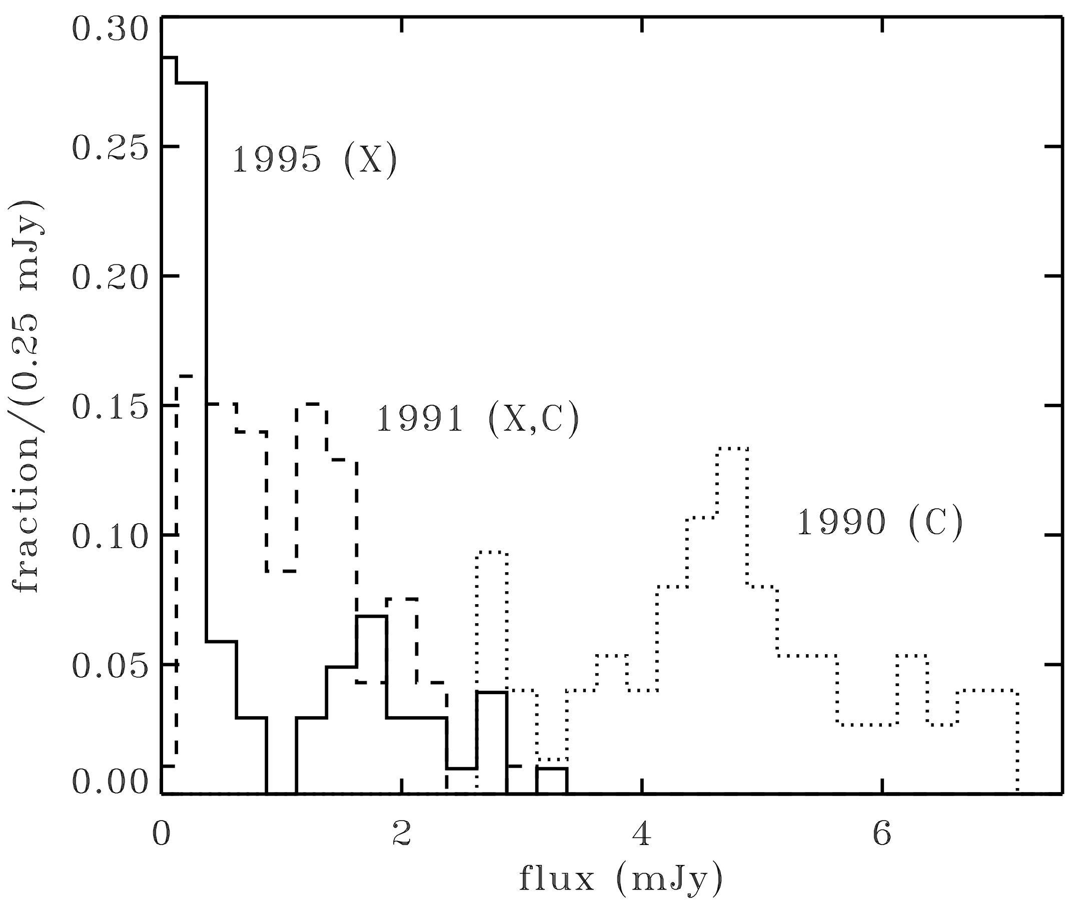

Fig. 3.— The histograms of the radio fluxes for observations of ER Vul in 1990 (dotted line), 1991 (broken line) and 1995 (continuous line). Note that the 1990 were obtained in the C-band (6 cm) whereas the 1991 and 1995 runs were in the X-band (3.6 cm). Checks conducted during the 1991 run indicated that the C- and X-band flux levels were practically identical at that time.

Table 1. 3.6 cm VLA Observations of ER Vul in 1995

JD (IAT) −2449980	flux (mJy)	JD (IAT) −2449980	flux (mJy)	JD (IAT) −2449980	flux (mJy)
4.404	0.31	4.757	1.70	7.572	−0.21
4.414	0.25	4.767	1.57	7.582	0.06
4.424	0.05	4.778	1.51	7.594	0.19
4.435	0.26	4.788	1.54	7.605	0.19
4.445	0.30	4.799	1.48	7.615	0.22
4.456	0.32	4.810	1.70	7.625	0.23
4.466	0.36	4.821	1.85	7.636	−0.19
4.476	0.02	4.831	2.25	7.646	0.04
4.487	−0.13	4.841	2.30	7.657	0.27
4.497	0.24	4.852	2.45	7.667	0.15
4.508	0.56	4.862	2.82	7.677	0.22
4.518	0.41	4.873	2.71	7.688	0.16
4.528	0.36	4.883	2.98	7.698	0.16
4.539	0.21	4.893	3.42	7.709	−0.03
4.549	0.39	4.904	2.86	7.719	−0.15
4.559	0.35	4.914	2.80	7.729	0.16
4.570	0.29	4.924	2.44	7.740	0.38
4.580	0.28	7.392	0.28	7.750	0.27
4.591	0.20	7.405	0.04	7.760	0.05
4.601	0.27	7.416	0.07	7.771	−0.04
4.611	0.48	7.427	0.00	7.781	−0.16
4.622	0.32	7.437	0.42	7.792	−0.01
4.632	0.50	7.447	0.74	7.802	0.23
4.643	0.72	7.458	0.36	7.812	0.30
4.653	0.84	7.468	0.03	7.823	0.26
4.664	0.90	7.479	0.39	7.833	0.23
4.674	0.97	7.489	−0.02	7.844	0.35
4.684	1.36	7.499	0.25	7.854	0.38
4.695	1.78	7.510	0.24	7.864	0.31
4.705	1.84	7.520	0.46	7.875	0.67
4.715	1.99	7.530	0.01	7.885	0.64
4.726	1.94	7.541	0.03	7.895	1.26
4.736	2.04	7.551	0.24	7.906	1.78
4.746	2.03	7.562	0.42	7.916	1.78